RESEARCH DEPARTMENT

AN INSTRUMENT FOR RECORDING THE FREQUENCY OF THE PUBLIC ELECTRICITY SUPPLY

Report No. T-115

(1963/45)

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SUMMARY

Many technical considerations connected with television broadcasting require a knowledge of the daily variations in the frequency of the public electricity supply. Due to the greatly improved stability of the frequency of the supply during recent years, the information provided by existing methods of recording the frequency has proved to be insufficient and the decision was made to design and construct a new instrument. The important aspects of the design of the instrument are discussed. The method of presenting the results is described and examples of recent statistics are given.

1. INTRODUCTION

Most parts of the United Kingdom, excluding Northern Ireland, are linked by the National Grid System and receive a supply of mains electricity at a common nominal frequency of 50 cycles per second. In the British television system, it has long been the practice to lock the field frequency of the video signal to that of the public electricity supply, an arrangement which has come to be known as 'synchronous working'.

Any mains-driven apparatus employed in the transmission or reception of television signals can exhibit interference from its own mains supply; this is usually manifest by positional and brightness disturbances in the received picture. It has been found that this interference has minimum visibility when the television field frequency is precisely equal to that of the mains.

Experiments have been carried out[1] in which numbers of domestic television receivers were operated from a variable-frequency supply, instead of the normal mains supply. Subjective tests showed that if the receivers were operated from a supply whose frequency differed by 0·2 c/s or more from the field-scanning rate, an annoying disturbance of the picture was visible on a significant proportion of the receivers tested.

Certain technical considerations, colour television in particular, make it desirable to operate the television system at a precisely-controlled field frequency instead of using the mains supply frequency as a reference. Such an arrangement is known as 'asynchronous working' and, in order to estimate the effects of this on receiver performance, it is clearly necessary to make a close study of the manner in which the mains frequency varies during television viewing hours.

In 1955, a machine was set up to record the frequency of the mains supply at Kingswood Warren during television broadcasting hours. The machine was a commercially manufactured, electro-mechanical pen recorder with a frequency range from 47 to 51 c/s. In addition, two recording hour-meters associated with the recorder were arranged to be switched on whenever the deviation in mains frequency from 50 c/s exceeded 0·1 c/s and 0·2 c/s respectively. Since 1956, the resulting records have been circulated, with the information sorted into the following categories:

Percentage of the total time when the error in frequency was less than 0·1 c/s.

Percentage of the total time when the error in frequency lay between 0·1 and 0·2 c/s.

Percentage of the total time when the error in frequency was greater than 0·2 c/s.

Fig. 1 shows the percentages in the second and third of these categories plotted at intervals between 1956 and 1961.

It can be seen that the stability of the mains frequency has improved considerably during these five years, due, no doubt, to the greatly increased generating capacity available. This fact, coupled with the results of the experiment referred to earlier, led, in 1961, to the decision to construct a new frequency-recorder which could provide the more detailed information required to examine the practicability of asynchronous working.

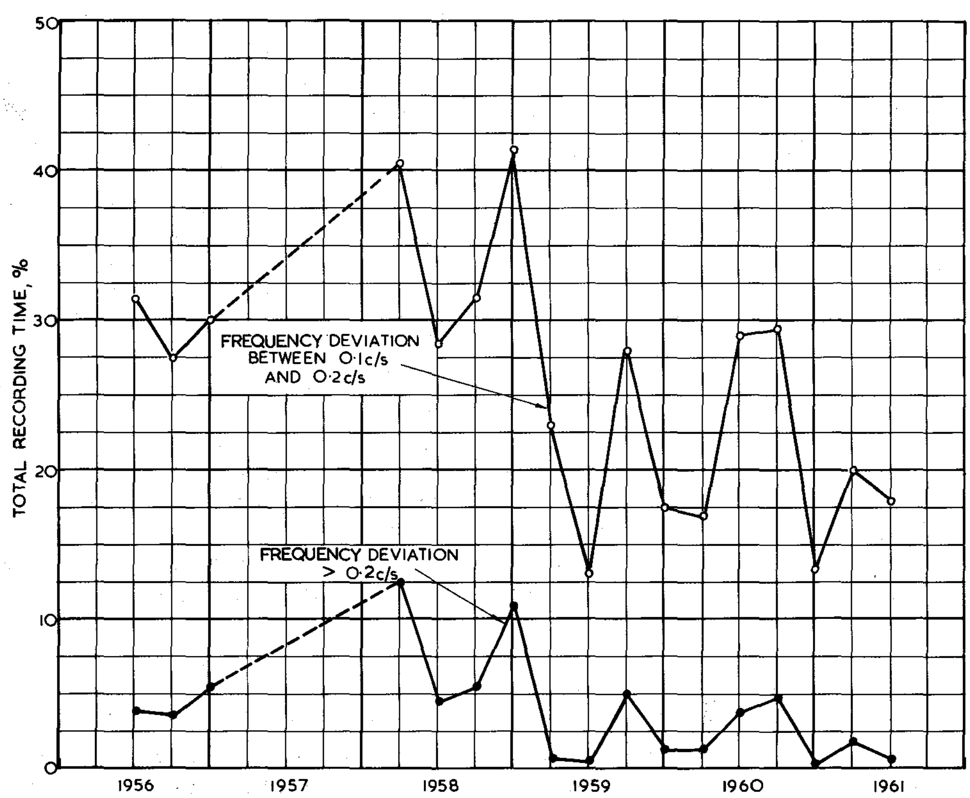


Fig. 1 - Deviations of mains frequency - 1956/61

2. GENERAL DESIGN CONSIDERATIONS

2.1. Required Information

In order that more detailed information might be obtained, it was necessary to reduce the frequency range to be covered by the instrument and to divide it into a greater number of discrete frequency levels than the total of three used previously.

It was also thought desirable that some form of 'time-of-day' information should be recorded along with the frequency record, to enable a separate analysis to be made of the behaviour of the mains frequency during those times of the day when it is likely that a large number of people are viewing television.

The design of an instrument was considered, therefore, which would provide a continuous record of the mains frequency and would also indicate in what part of the day any particular frequency measurement was made.

2.2. The Sampling System

The measurement of a frequency of about 50 c/s (with an accuracy of, say, ± 0·02 c/s) by the use of frequency-selective circuits clearly involves components having a high degree of accuracy and stability. A better approach is to count the number of cycles (or half-cycles) of the mains waveform which occur in a given time interval, since such a count may be obtained by the use of simple aperiodic circuits. The quantized measurements so obtained are suitable for statistical analysis.

An examination of previously obtained results showed that the deviation of mains frequency from the nominal value of 50 c/s rarely exceeded 0·25 c/s in either direction, thus indicating that an overall range of 0·5 c/s would suffice. It was also found that the maximum rate-of-change of mains frequency did not normally exceed 0·025 c/s per minute. If, therefore, a measurement of mains frequency were to be made, say, once per minute, the measuring instrument should be capable of resolving a change in frequency of 0·025 c/s or less. This requirement influences the duration of the period during which the number of half-cycles of the mains waveform is to be counted and thereby determines the number of different levels within the given frequency-measurement range.

As will be seen in Section 2.3., the use of a 5-digit data-tape recorder accommodating 32 levels per character meets these requirements. The duration of the counting period is fixed at precisely 30 seconds and a count of 3000 half-cycles is produced when the frequency of the mains is exactly 50 c/s. One half-cycle more, or less, represents a change in mains frequency of 0·0167 c/s and a counting range of 3000 ± 15 half-cycles can be accommodated by 31 recorded levels; the total frequency-range of 0·5 c/s is thus covered.

Since the frequency quantum chosen is less than 0·025 c/s and a new measurement is made each minute, the highest rates of change of frequency likely to occur can be recorded satisfactorily.

In order that the range of the instrument might be increased from 0·5 c/s to 1·0 c/s, should this be required for any reason, provision has been made to count whole cycles of the mains waveform, instead of half cycles. If, under these special circumstances, the frequency being recorded is exactly 50 c/s, a total of 1500 cycles is counted in the 30 second period and the frequency quantum becomes 0·033 c/s.

2.3. Form of Data Recording

In the instrument described here, the half cycles of the mains waveform are counted in the form of pulses occurring at the rate of approximately 100 per second, but since the recording range is limited, the counter circuits used need only have a limited capability. This fact will be appreciated when it is realised that the total number of pulses occurring in 30 seconds is always fairly close to 3000, and a counter capable of counting any number from zero up to 3000, or more, would merely accumulate a large amount of redundant information. During the counting process, therefore, a counter of smaller capability is arranged to pass through a large number of complete counting cycles, only the last, partially completed, count being permanently registered. Using simple binary counters, five stages are required to give a capacity of 31. In fact, seven binary-counting stages are used so that, in the event of a pulse-count lying outside the recording range of the 5-digit data-tape and hence outside the range of the instrument, one or other of the two extra counter stages is operated. By using 31 of the 32 available levels for the frequency record, one level remains available to record a special out-of-range condition on the data-tape. The use of paper-tape 'print-out' allows additional information, such as the time of the measurement, to be recorded along with the result of the frequency measurement. This permits the data to be analysed by automatic means.

A paper-tape punching mechanism of a standard type manufactured by Creed and Co. Ltd. is used. It employs an arrangement whereby a particular 5-digit coded number is punched by the mechanism if the appropriate solenoids are energized.

Equipment for the analysis of punched paper tape already existed in the Field Strength Section of Research Department and this facility was made available when the frequency-recorder was first completed. Substantial benefit was also derived from the experience of Field Strength Section in the use of tape-punching techniques in operational equipment.[2]

The 5-digit paper tape is suitable for use by an electronic computer, and this method of analysis has now been adopted.

2.4. Derivation of the Measurement Interval

The accuracy of the derived statistics depends on the precision with which the counting interval is determined and this, therefore, was a very important factor in the design.

Of the various systems available, the best combination of reliability and accuracy was considered to be a crystal oscillator coupled with the necessary binary scaling or dividing stages. This technique also permits other signals to be generated whose periods bear a fixed relationship to the half-minute measurement interval and which can be used for test or other purposes.

2.5. Provision of Checking Facilities

As a means of keeping a continuous check on the long-term accuracy of the crystal frequency, it was decided to monitor the frequency at an intermediate point in the chain of dividers following the crystal. This chain was arranged, therefore, to

give an output at 50 c/s; this, in turn, was amplified and used to drive a conventional synchronous electric clock. Regular comparisons between the time indicated by this clock and the time-signals from Greenwich thus provide a convenient measure of the long-term accuracy of both the crystal-oscillator frequency and the division ratio relating this frequency to 50 c/s.

Provision has also been made to feed the same crystal-derived local 50 c/s signal to the counters in place of the normal mains-frequency signal, thus checking the operation of the equipment subsequent to the 50 c/s point in the divider chain. This facility is made available by means of a test-button and results, in normal circumstances, in a count corresponding to precisely 50 c/s. The paper tape may then be inspected in order to confirm that the count has been punched correctly.

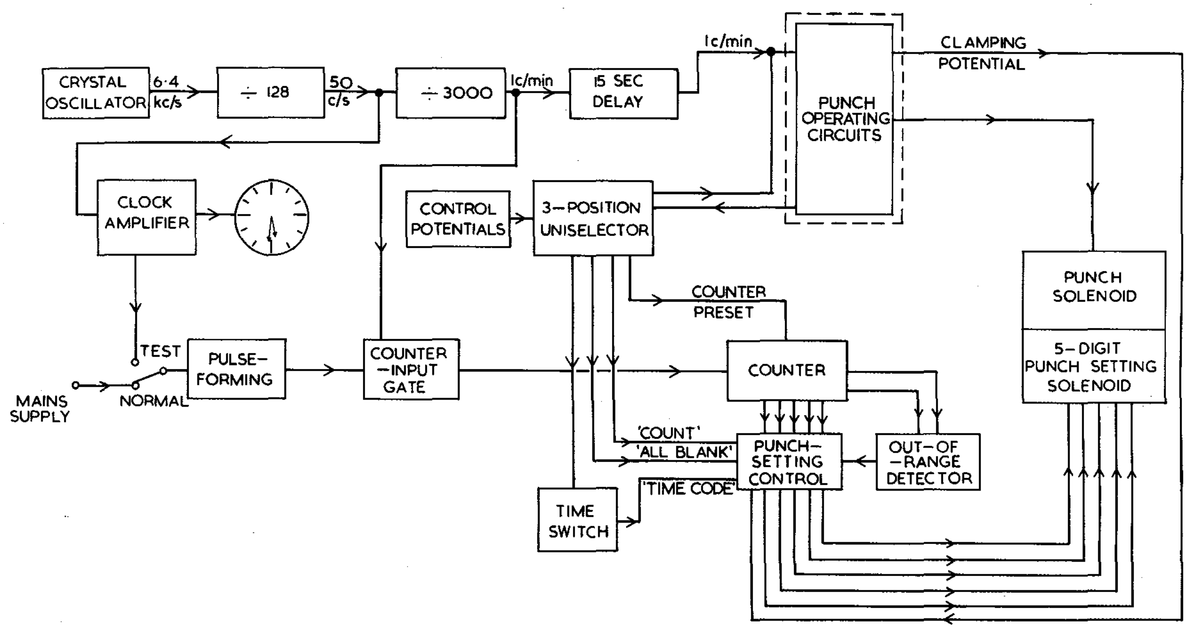


Fig. 2 - Diagram of the complete recorder

3. THE COMPLETE RECORDER

Fig. 2 shows the block schematic diagram of the complete recorder and a photograph of the apparatus is given in Fig. 3. The output from a temperature-controlled 6·4 kc/s crystal oscillator is divided in frequency by 128 to give two square-wave outputs at 50 c/s. One output is used to drive a clock amplifier that produces a 220 V, 50 c/s sine-wave output which, in turn, is used to drive a conventional synchronous electric clock. The other output is further divided in frequency by 3000 to obtain a square-wave having a frequency of 1 c/min. One half-cycle of this wave corresponds to the measurement interval and is used to gate the train of pulses forming the input to the counter, the gate thereby being opened for precisely 30 seconds in each minute.

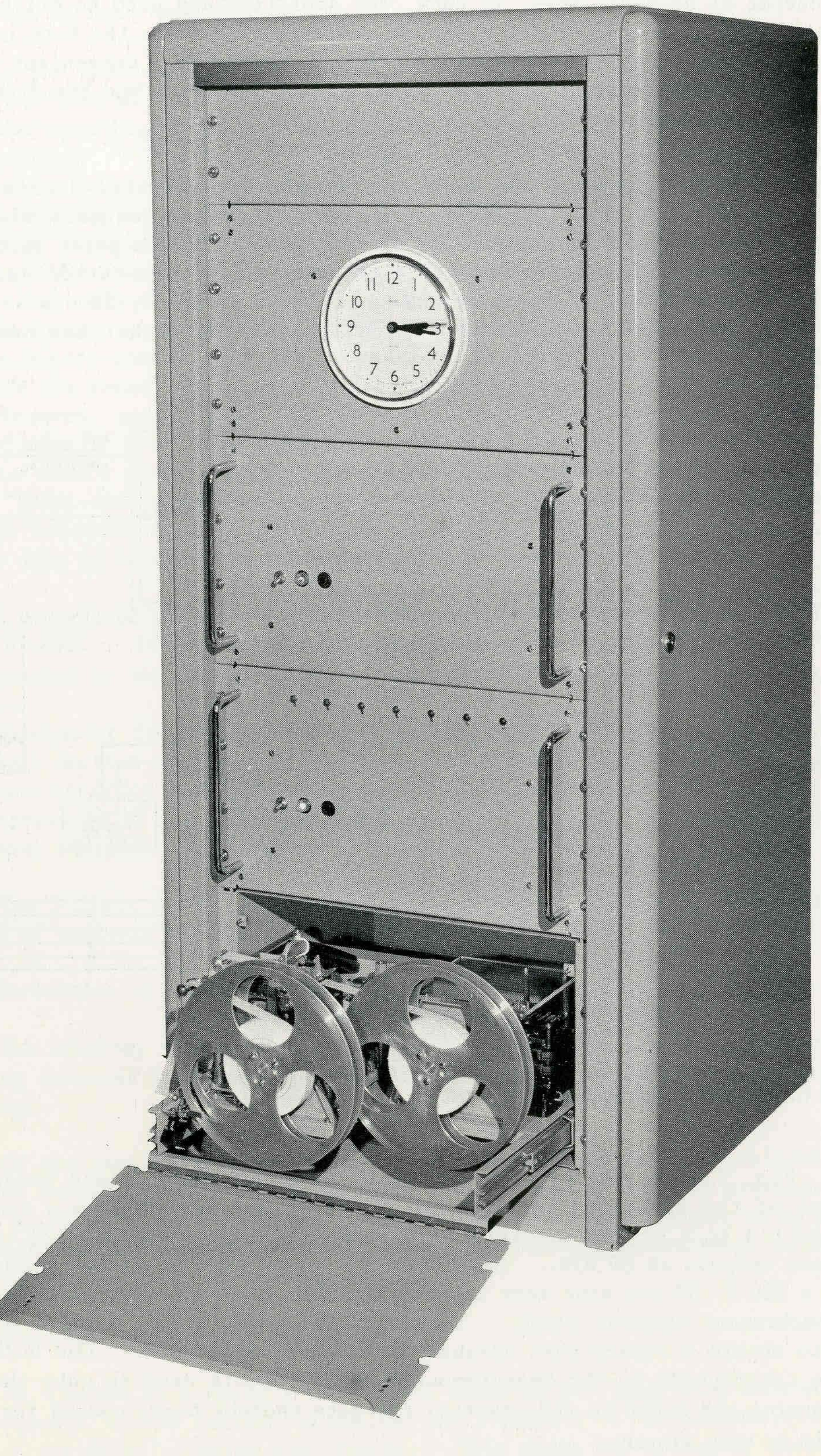


Fig. 3 - View of the complete recorder

The pulses to be counted are derived via a pulse-forming unit, either from the mains supply (in normal operation) or from the clock amplifier (for test purposes). As mentioned previously, the pulse-forming network can provide either one or two pulses per cycle of the a.c. input, but in order to simplify the description, it will be assumed, in the remaining sections of this report, that the pulses occur at the preferred rate of two pulses per cycle of the mains input waveform, the corresponding frequency-range of the instrument being 0·5 c/s.

The 1 c/min. gating signal which controls the 30-second counting period is also fed to a delay-unit so as to produce a pulse occurring fifteen seconds after the count has ended. This pulse is applied to the main punch-operating unit where it is delayed by a further 0·2 seconds, during which time an 'inhibiting' potential is removed from the punch-setting control circuits permitting information stored by the first five binary counters to reach the five punch-setting solenoids. Each solenoid is thus either energized or de-energized according to the condition of the appropriate counter, the state of each counting stage having remained unchanged since counting ceased some 15 seconds earlier. The main punch solenoid then operates the paper-punching mechanism and produces, on the tape, a punched code corresponding to the condition of the counters.

After this first operation of the punch, a pulse from the punch-operating unit is used to move a three-position uniselector from its first to its second position and an inhibiting potential is again applied to the punch-setting control circuits, isolating the punch-setting solenoids from the counters.

Upon reaching its new position, the uniselector feeds back a pulse to the punch-operating unit, again removing the inhibiting potential. This time, however, it is replaced by a control potential from the uniselector, which causes all the punch-setting solenoids to be de-energized. The punch now operates again, producing an 'all-blank' record on the tape. The uniselector is then moved to its third position and the inhibiting potential is restored.

On arriving in its third position, the uniselector causes the condition of the punch-setting solenoids to be governed by control potentials obtained from a four-position time-switch, enabling a time-code to be recorded on the tape by a third operation of the punch. Finally, the uniselector moves to its rest position; it has now completed its operating cycle and does not produce a further re-cycling pulse. The uniselector, the solenoids, and the punch-setting and operating circuits then remain inoperative for almost a minute during which time the next 30-second count takes place.

One further task performed by the uniselector is to supply a potential which re-sets the counters in preparation for the next counting period. This occurs when the uniselector is in the 'all-blank' punching position.

The counter unit contains, in all, seven binary counters, the first five of which are connected to the punch-setting solenoids during the appropriate part of the recording cycle, as already described. The outputs of the last two binary counters are used to detect any pulse count which falls outside the range of the first five.

In such an event, the out-of-range detector feeds, to the punch-setting control circuits, an 'all-blank' signal that replaces the normal information from the counters. An 'all-blank' is thus punched on the tape in the place normally occupied by the pulse count.

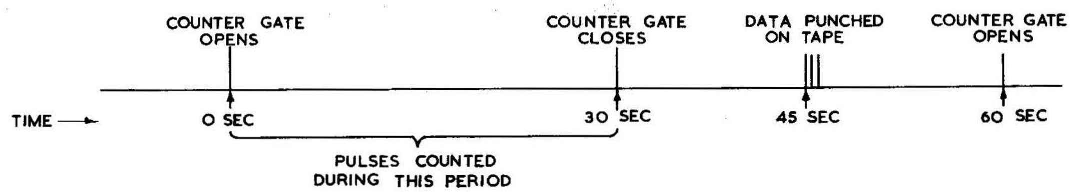


Fig. 4(a) - The one minute counting and recording cycle

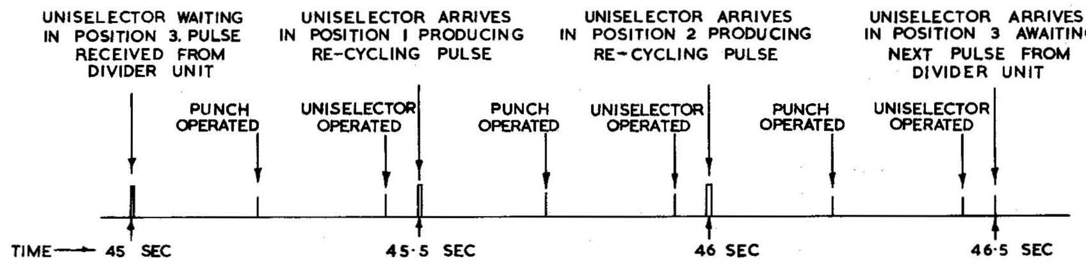


Fig. 4(b) - Detailed diagram of the data recording period

Fig. 4 shows the one-minute cycle of the recorder, together with an enlarged diagram of the 1½-second punching period.

This instrument employs a large number of relatively complex electronic circuits in order that the many operations may be performed and timed within the recording cycle. No attempt has been made in this report, however, to describe the circuits in detail, since they are based upon well-known techniques.

4. PERFORMANCE

Since the recorder was completed in November 1961, the electronic performance has been satisfactory and, apart from a few short breaks due to mechanical faults in the perforator, a continuous recording has been made of the frequency of the public electricity supply.

The data-tape output has been analysed either by means of the manual analyser or, more recently, by an Elliott 803B computer. From the information obtained in this way, quarterly statistics have been published and these are described in Section 5.

The accuracy with which the instrument measures and records the mains frequency is clearly dependent on the accuracy of the 30-second counting period. Even if this period were of precisely 30 seconds' duration, however, it would still be possible for any single count to be in error by one pulse. This would result when the counting period either starts or finishes coincident with a pulse in the mains-

frequency pulse train. When a large number of counts are made, these errors tend to cancel and the accuracy of the information depends principally on that of the counting period and hence on the crystal-oscillator frequency.

A convenient rough check on the operation of the instrument makes use of the fact that the Central Electricity Generating Board endeavour to maintain the average mains frequency at a figure very close to 50 c/s. If this were not the case, the vast number of electric clocks in use throughout the country would gradually build up a considerable error. The average frequency obtained from the 20,160 measurements made by the recorder during the first two weeks of its operational life was, in fact, 50·00024 c/s; an error of this magnitude would result in electric clocks gaining less than 6 seconds during the two-week period, which, of course, is well within the normal tolerances.

In order to keep a continuous check on the oscillator frequency, a record is kept of the difference in time between the crystal-driven clock and a reference obtained from either the Greenwich time signal or some other time standard. The fine frequency control of the oscillator was adjusted over a period of months until the clock error varied by less than one half-second per twelve weeks. This represents a frequency accuracy of better than 1 part in 10^7 and it is to this accuracy that the supply frequency is recorded. The temperature inside the crystal enclosure is found not to vary by more than ± 1°C.

5. PRESENTATION OF ANALYSED RESULTS

At the end of each quarter's recording, the data-tapes are analysed. The analysis gives the number of times each frequency-level available within the normal range of the instrument has been recorded, together with the total number of measurements indicating frequencies that are outside the range. The information given in the published results is divided into two sections. The first of these gives the number of times each frequency-level occurs during the 24 hours of each day and the second gives the number of those that occur during the important viewing hours, i.e., 1900 to 2300 hours on weekdays and 1430 to 2300 hours on Saturdays and Sundays.

5.1. Histograms

By plotting the number of recorded occurrences of each stated frequency-level, a histogram is produced. Separate histograms are plotted for the 24-hour period and for the important viewing hours.

Fig. 5 shows examples of the histograms taken from a recent quarter and these give a general overall picture of the behaviour of the public electricity supply.

5.2. Cumulative Distribution Curves

In order to obtain a plot from which the percentage of the total time that the frequency was greater or less than a given value may be assessed directly, cumulative distribution curves are plotted on arithmetic-probability paper.

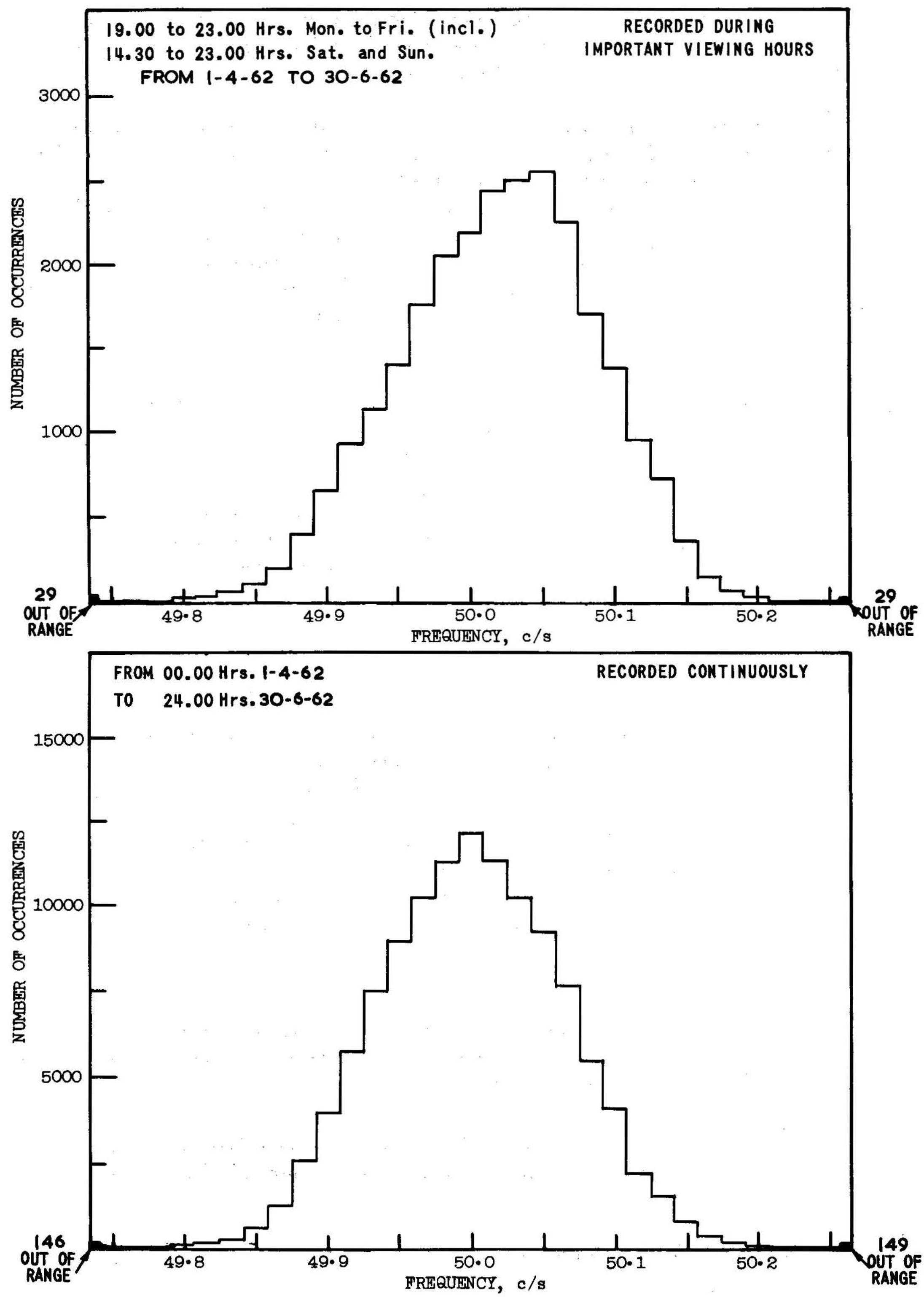
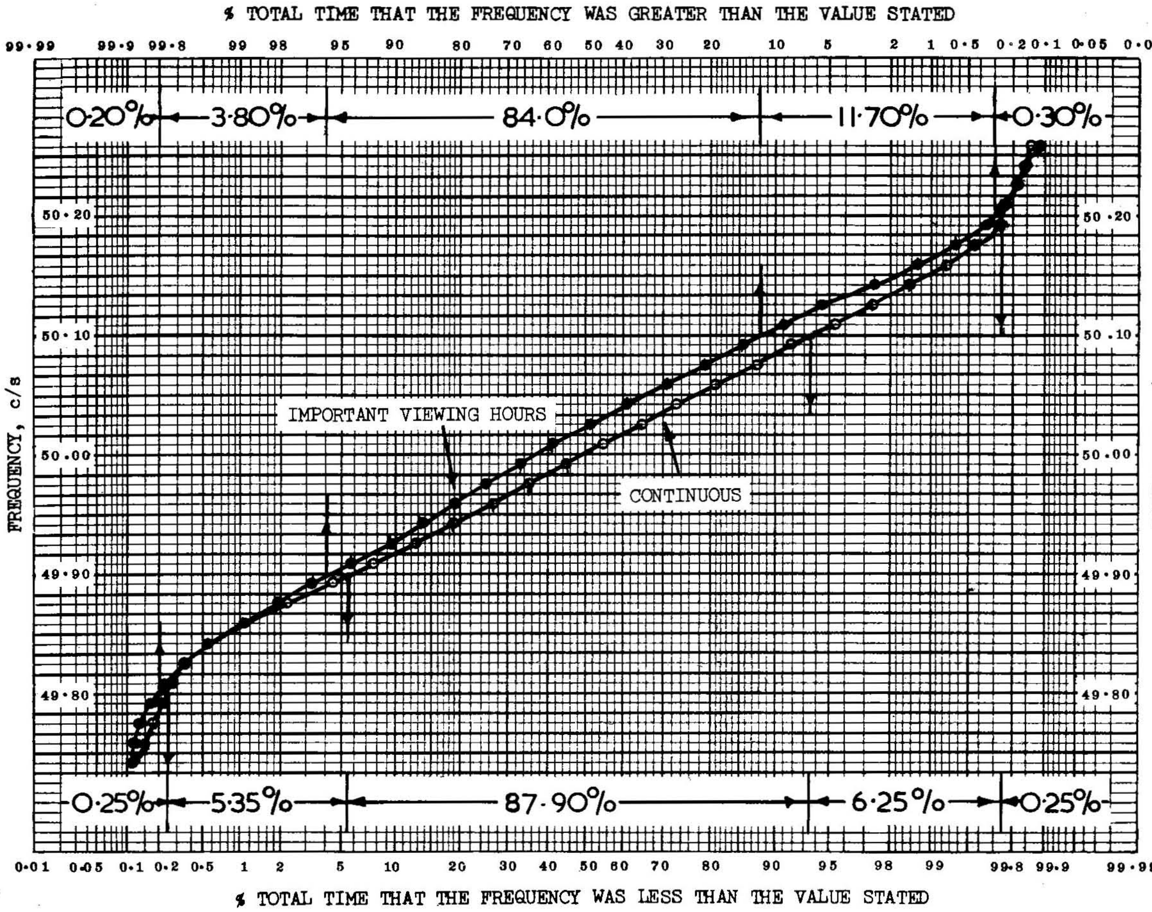


Fig. 5 - Analysed results - histograms



RECORDING MADE DURING IMPORTANT VIEWING HOURS

19.00 to 23.00 Hrs. Mon. to Fri. (incl.)
14.30 to 23.00 Hrs. Sat. and Sun.
FROM 1-4-62 TO 30-6-62

CONTINUOUS RECORDING

FROM 00.00 Hrs. 1-4-62
TO 24.00 Hrs. 30-6-62

Fig. 6 - Analysed results - cumulative distribution

Once again separate graphs are drawn for the 24-hour period and for the important viewing hours; Fig. 6 shows cumulative distribution curves corresponding to the histograms of Fig. 5.

It will be observed that the plotted points on these curves are shifted along the frequency axis, by an amount equal to half one recorded step, with respect to the centres of the corresponding blocks of the histograms. This is due to the fact that frequencies recorded as being, say, 50 c/s may have had any value within ± 0·0167 c/s of this figure. When plotting a cumulative distribution curve where the recorded frequency is shown as being greater or less than a particular value, it is necessary to allow for the fact that the recorded number of occurrences attributed to a particular frequency actually consists of the total number of occurrences of frequencies within half a measuring quantum on either side of the specified frequency.

TABLE 1

Analysed results - statistics

(Obtained from Cumulative Distribution Curves)

Frequency Deviations from 50 c/s

RECORDING MADE DURING IMPORTANT VIEWING HOURS

19.00 to 23.00 hrs. Mon. to Fri. (incl.)
14.30 to 23.00 hrs. Sat. and Sun.

FROM 1-4-62 TO 30-6-62

Less than 0·1 c/s	84·00 % total time
Between 0·1 c/s and 0·2 c/s	15·50 % total time
Greater than 0·2 c/s	0·50 % total time

CONTINUOUS RECORDING

FROM 00.00 hrs. 1-4-62.
TO 24.00 hrs. 30-6-62.

Less than 0·1 c/s	87·90 % total time
Between 0·1 c/s and 0·2 c/s	11·60 % total time
Greater than 0·2 c/s	0·50 % total time

The percentages of the total time that the deviation of the mains frequency from 50 c/s exceeded 0·2 c/s on the one hand and lay between 0·1 and 0·2 c/s on the other hand, are obtained from these graphs. The statistics are shown in Table 1 and represent frequency deviations in both directions. Mains-frequency statistics, in the form shown in Table 1, have been published periodically since 1956.

6. ACKNOWLEDGEMENT

The authors of this report wish to acknowledge the co-operation and advice provided by Mr. D.E. Susans of Field Strength Section, Research Department, particularly in connection with the design of the counting and punch-operating circuits used in the instrument.

7. REFERENCES

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2. 'Equipment for Medium Distance Propagation Tests in Bands I and II', Research Department Report No. K-156, Serial No. 1962/42.

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